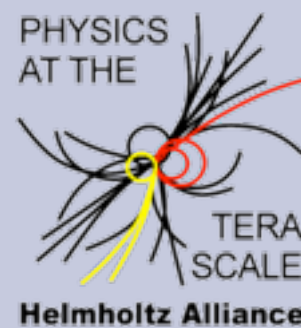




MPII meets OpenMP™

C. Kleinwort

DESY/HH alignment meeting 11.05.10

OpenMP™

★ Mission

- ▶ The OpenMP Application Program Interface (API) supports multi-platform shared-memory parallel programming in C/C++ and Fortran on all architectures, including Unix platforms and Windows NT platforms. Jointly defined by a group of major computer hardware and software vendors, OpenMP is a portable, scalable model that gives shared-memory parallel programmers a simple and flexible interface for developing parallel applications for platforms ranging from the desktop to the supercomputer.

★ Details on OpenMP.org

★ Implemented in gcc4 as 'gomp', SL5:

```
F_FLAGS += -fopenmp  
C_LIBS  += -lgomp
```

Use case

★ MINRES

- Solution method for large number of parameters
- Full or sparse storage

★ Most time spent in AVPROD

$$\mathbf{b} = \mathbf{A}_{\text{sym}} \cdot \mathbf{x}$$

- Multiply global matrix by vector
- Once per MINRES internal step
- CRAFT09, 150k parameters (sparsity 10%):
~6s on DESY WGS

★ Parallelize loop in AVPROD using OpenMP

AVPROD (serial, optimized)

★ Example for full (triangular) storage

IJ=0 ! full symmetric matrix

DO I=1,N ! diagonal

B(I)=DQ(INDJ/2+IJ+I)*X(I)

DO J=1,I-1 ! off-diagonals

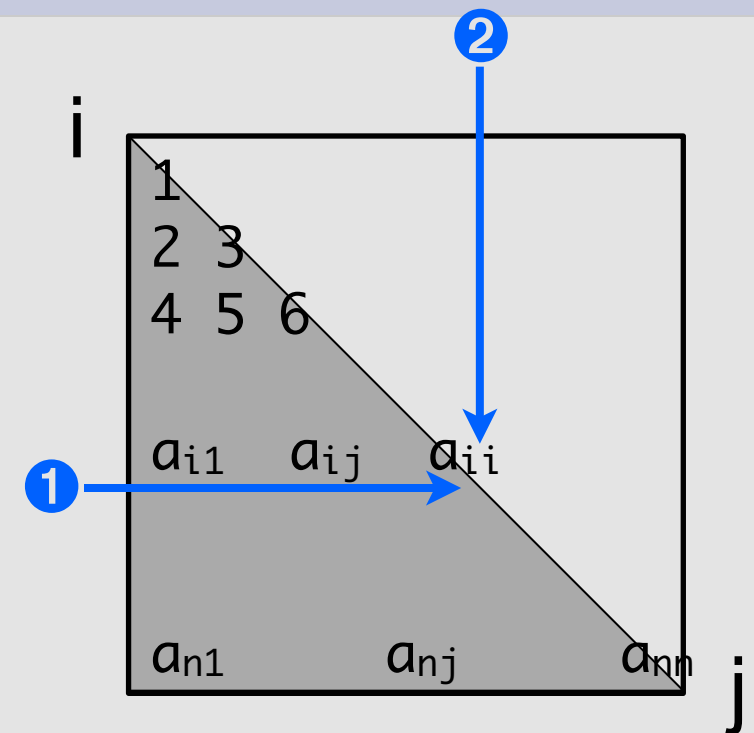
① B(I)=B(I)+DQ(INDJ/2+IJ+J)*X(J) ! relies on initialization

② B(J)=B(J)+DQ(INDJ/2+IJ+J)*X(I) ! of B(J) by previous I=J

END DO

IJ=IJ+I ! depends on (sum of) previous values of I

END DO



► Same B() updated in different iterations

✦ Different threads would write to same memory location !

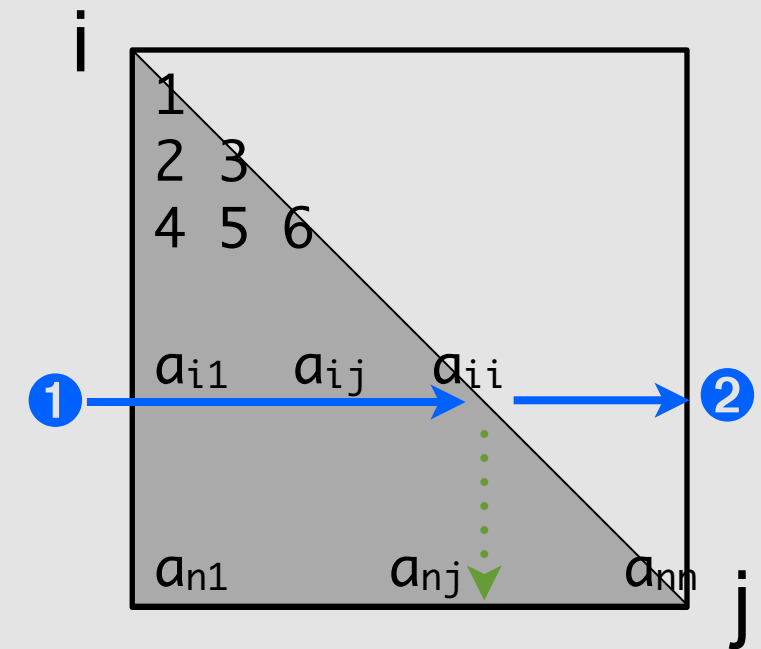
AVPROD (thread save)

★ No 'overlap' with other iterations

```

DO I=1,N          ! everything in loop
  IJ=I*(I-1)/2    ! depends only on current I
  B(I)=0.
  DO J=1,I        ! 'direct' elements
    IJ=IJ+1
    ① B(I)=B(I)+DQ(INDJ/2+IJ)*X(J)
  ENDDO
  DO J=I+1,N      ! 'mirror' elements
    IJ=IJ+J-1
    ② B(I)=B(I)+DQ(INDJ/2+IJ)*X(J)
  END DO
END DO

```



- ▶ Sparse storage: no easy access to mirror elements
 - ✦ Would need second sparsity structure
- ▶ Instead use copy(B) local to thread, combine at end

AVPROD (parallel)

★ Using OpenMP™

```
      DO I=1,N
        B(I)=0.                ! reset 'global' B()
      ENDDO

!$OMP PARALLEL DO              ! parallelize row loop
!$OMP& PRIVATE(IJ)            ! variables local to thread (incl. I,J)
!$OMP& NUM_THREADS(..)        ! number of threads
!$OMP& REDUCTION(+:B)          ! private copy of B(N) for each thread
!$OMP&                        ! combined ('+') at end, init with 0.
!$OMP& SCHEDULE(DYNAMIC,1024) ! slot of 1024 'I' for next idle thread
      DO I=1,N                ! full symmetric matrix
        IJ=I*(I-1)/2          ! depends only on current value of I
        B(I)=DQ(INDJ/2+IJ+I)*X(I) ! diagonal
        DO J=1,I-1            ! off-diagonals
          B(J)=B(J)+DQ(INDJ/2+IJ+J)*X(I)
          B(I)=B(I)+DQ(INDJ/2+IJ+J)*X(J)
        END DO
      END DO
!$OMP END PARALLEL DO
```

Performance

- ★ Code modifications for 'thread safety'
 - Loss of optimization ?
- ★ Overhead from thread management
 - Initialization, synchronization, ..
- ★ CRAFT09, 260k tracks, 150k parameters

#threads	CPU time [min]	wall time [min]	ratio [%]
serial	276	277	100
1	277	278	100
2	277	150	185
3	314	120	262
4	342	104	329

MINRES convergence

- ★ Controlled by tolerance parameter $RTOL=10^{-8}$
 - ▶ Too small ?
 - ▶ Steerable with ‘mrestol r_{tol}’
- ★ Check with CRAFT09 data (3 threads, 6 iterations)

r _{tol}	#steps	CPU time [min]	wall time [min]	χ^2
10^{-8}	2742	314	120	2485038.918
10^{-7}	2057	264	97	2485038.920
10^{-6}	1359	166	70	2485038.920
10^{-5}	727	99	48	2485042.515
10^{-4}	357	60	36	2485067.986

Summary

★ Parallelization with OpenMP™

- ▶ Implemented for 'sparseMINRES' in AVPROD
- ▶ Significant reduction of wall time
- ▶ New option
 - ✦ 'threads n_{thread} '

★ Minres convergence

- ▶ Increase of r_{tol} to 10^{-6} seems feasible



Examples

New features in MPII 3.2

CRAFT09, 260k tr., 150k par.

★ Steering file

On 4 core DESY WGS

```
method sparseMINRES 6 0.8 ! sparse storage, MINRES
threads 3 ! with 3 threads for AVPROD
compress ! compressed sparsity info with
pairetries 1 15 10 ! single prec. up to 10 entries
```

★ Pede output

Millepede II-B starting ... Fri May 7 07:11:01 2010

NDBITS: number of used off-diagonal elements 1223342834
NDBITS: compression ratio for off-diagonal elements 36.56 %

used 5.413202 GB = 63.02 %

Chi²/Ndf = 2485038.91757623 / 3541440 = 0.7017030

4 h 46 min 53.3 sec total elapsed 4 h 38 min 58.5 sec

< Millepede II-B ending ... Fri May 7 09:02:35 2010

CRAFT10, 1M tracks, 200k par.

★ Steering file

On 8 core DESY NAF

```
method sparseMINRES 6 0.8 ! sparse storage, MINRES
threads 6 ! with 6 threads for AVPROD
compress ! compressed sparsity info with
pairetries 1 0 5 ! single prec. up to 5 entries
```

★ Pede output

Millepede II-B starting ... Sun May 9 10:59:46 2010

NDBITS: number of used off-diagonal elements 3066357472
NDBITS: compression ratio for off-diagonal elements 39.91 %

used 14.744258 GB = 92.15 %

CPE
WithAngle Chi^2/Ndf = 15926382.8760041 / 14642566 = 1.087677

14 h 57 min 25.6 sec total elapsed 14 h 30 min 35.9 sec

< Millepede II-B ending ... Sun May 9 15:40:38 2010